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Review Article

Current Concepts in the Surgical Treatment of Charcot Foot Arthropathy: A Scoping Review of the Literature

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Abstract

Charcot's foot neuropathy is a complex disease encompassing a broad spectrum of conditions varying from progressive deformity to joint collapse with fragmentation and infection. To tackle this challenging condition, reconstructive surgeons deploy methods and implants that transcend the conventional approaches. Even though there is significant progress in understanding the natural history, pathologoanatomy and biomechanics, the surgical treatment is still controversial and lagging, based upon weak or moderate evidence. Most notably, the timing of the intervention and the mode of fixation is a topic of debate and controversy among the experts.

***Keywords:** Reconstruction, fixation, Charcot foot, beaming, superconstructs*

Introduction

Charcot foot deformity is a progressive destructive process that affects diabetic patients with loss of protective sensation primarily.

The common sequela is the deterioration of the foot architecture, collapse and debilitating deformity [1,2,3]. In front of this challenging condition, the treatment should focus on restoring the functional capacity and stability, thus preventing the spiralling leading to ulceration, infection, and finally amputation.

The deformities caused by this disease are often multi-level and multi-axial, and operative planning is challenging upon the background of ulceration, osteomyelitis and bone destruction. Internal and external fixation techniques and their combination are included in reconstructing the broad spectrum of deformities. It is not yet clear amongst the experts which method constitute the golden standard, and the respective current scientific evidence is scarce.

This manuscript aims to review insights from the current literature and surgical experience and discuss trends and considerations regarding the surgical fixation modalities.

Management of diabetic neuroarthropathy

In contemporary times, the demographics have changed dramatically; it is a fact that diabetes mellitus has become the most common cause of Charcot neuropathy; the incidence is about 0.1% to 5% in diabetic neuropathy and constitutes a concerning complication which increases the morbidity and mortality of diabetic patients [1,2].

Traditionally, the primary treatment of acute Charcot disease is usually non-operative, primarily deploying off-loading techniques such as total-contact casting (TCC) or similar orthotic appliances (for example, CAM boots)[5,6]. The standard practice is utilising this therapeutic modality during the acute and active stage of the disease as a temporising method. Recently this concept has been challenged. Some authorities endorse early surgical stabilisation even during the stage of fragmentation of the Charcot arthropathy.[10] However, this is a hot topic for debate and controversy among the scientific community, and more research needs to be conducted to reach a generally accepted consensus.

When there is significant deformity and instability that cannot be controlled with off-loading bracing, when ulceration occurs or is inevitable, surgical management is warranted in Charcot disease, especially when there is associated osteomyelitis or pain.

An MDT approach is warranted, and it is crucial for a holistic approach of the patient, including nutrition, vascular status, infection control, short- and long-term blood glucose management, and other factors requiring laboratory monitoring and consulting services. Once optimised, the deformity can be evaluated and assessed by biomechanical perspective and appropriate planning on the mode of the fixation and the devices.

Strategies of surgical treatment

The main goal of surgical reconstruction is to correct the deformity and restore the biomechanics of the foot. To elaborate, restoring the tripod construct is crucial; More specifically, the three main arches (the transverse, lateral and medial longitudinal) and thus reestablishing the "triangle of support".Cotton theorised this would, in turn, restore the biomechanics of weight-bearing [6,8].

Researchers have cited the reduction of Meary's angle as the most significant reconstruction principle. [7,8] In fact, Grant et el. has found that the overcorrection of Meary's angle produces the best 10-year survivability.[9] It is of paramount importance to include the aims of the surgical treatment to eradicate the infection, facilitate the healing process, prevent the risk of ulceration, and eventually achieve a stable, plantigrade and braceable extremity.

There is a broad spectrum of surgical options and techniques to achieve the objectives mentioned above. Because of the inherent challenges to Charcot's foot (e.g., inadequate bone stock, non- compliance, neuropathy, impaired healing, immunocompromised), a carefully planned and unique approach is warranted. Over the past decades, the "super constructs" [4] have been developed to obtain a successful arthrodesis in the Charcot's foot.

The concept of a super construct, according to Sammarco et al., consists of four basic tenets:

1. Fusion beyond the injury zone, offering longer lever arms,
2. Bone resection to accommodate reduction with minimal tension on the soft-tissue envelope,
3. The utilisation of the most robust implants and
4. Device positioning with multiple fixation points that maximises biomechanical stability.

Locking-plate, axial screw-fixation and planar-plating technologies are well-defined examples of the super construct concept. We will endeavour to categorise the mode of the fixations and the type of implants involved.

Internal fixation devices

The traditional l methods of reduction and fixation in the setting of the diabetic neuropathic foot are not eligible. Furthermore, the conventional hardware, for example, small fragment plates and screws, is most likely prone to early failure [4,10]. Thankfully are available specially designed implants, which utilises robust designs of the low profile yet strong, malleable plates combined with highly secure fixation screws and intramedullary devices (beams and bolts) that allow compression and biological healing.

Extramedular devices

Plating techniques have a long and well-established role in internal fixation. However, the traditional AO teachings have evolved and adapted to accommodate the challenging setting of the Charcot reconstruction. The emerging technologies and, especially, the newest generation of locking devices provide encouraging outcomes [11,12]. Allows a toggle-free, fixed-angle construct, which offers a friendlier environment to facilitate biological healing, allowing less soft tissue stripping and violation. Moreover, it allows better fixation on the pathologic, brittle bone and more predictable recovery. The locking devices will enable the concept of bridging, which circumvents the applied loads from the frail bone via proximal and distal fixation.

In biomechanical studies, the locked plate demonstrates equivalent fixation to the plantar construct, mitigating the risks of soft tissue complications when an extensile plantar exposure is utilised[13]. Furthermore, the locking plate technology can overcome the anatomic considerations while endeavouring the position of the plate.

The most common configuration is a medial and lateral plate to support and restore the respective columns. Many surgeons advocate for the plantar position of the plate[13]; it is a fact that the optimal position of the plate is still a topic of controversy and debate.

Intraraxial devices

The intramedullary devices are a relatively new technique introduced in the late 90s but contributed significantly to evolving and expanding the surgical options on Charcot foot reconstruction. These solid bolts or cannulated screws are operating by the principle of "cement rebar", as coined by Grant et al.[13], and offer a biomechanically durable and predictable fixation of the medial and lateral columns of the foot segments. A significant advantage is that they can be introduced with minimal incisions, soft-tissue sparring techniques, and their biological footprint is relatively minimal[15,16].

The common practice utilises either stainless steel bolts or cannulated screws, with the latter to be prefered by the surgeons because it is less technically demanding. These implants could be partially threaded, offering compression by design or fully threaded with the trait to increase the pull-out resistance and mitigate the risk of subsidence. Because the medial column fixation is subjected to cantilever bending moments and thus is more prone to fatigue failure, a medial locking plate combination is increasingly used [15,16]. Another school of thought uses a single solid stainless steel bolt which offers adequate stability. From the current literature body search, there is no study to compare these fixation methods and thus could be a new field of research.

An emerging concept is the titanium trusses used in the complex reconstruction with segmental bone loss or inadequate midfoot bone stock [17]. To elaborate, introducing the beams through a titanium mesh offers a wide range of theoretical advantages: The mesh imparts an additional modulus similar to the bone, osseointegration capacity, and a load-sharing supplementation that deflects the forces from the beam.

Recently the concept of high profile thread etched with grit-blasted surface has been introduced [18]. This modification, in theory, can mitigate the risk of loosening and migration by increasing the osteointegration and the stability of the fixation, expanding the bone ingrowth.

The early results seem promising, but longer-term longitudinal studies are required. Unfortunately, the beaming techniques are not free from complications; These can be summarised as infection, loosening with migration and loss of fixation, hardware failure, transfer lesion and deep infection, especially when full-thickness ulcerations are already present [15].

External fixation devices

The external fixator devices have expanded significantly the armamentarium of the surgeons managing the Charcot foot deformities. Static and dynamic external fixation apparatuses provide solutions in complex and severe cases. They allow appropriate soft tissue and infection management, gradual correction of even profound deformities and can be used as supplementation and enhancement of the fixation. The most prominent methods of fixation in contemporary practice are the Ilizarov apparatus and the Taylor spatial frame.

The Ilizarov ring fixator (IRF)has attained a prominent position in the reconstruction modalities. It provides a unique array of features and facilities; Multi-axial fixation axial compression with robust circumferential support allows immediate weight-bearing. Furthermore, it is technically demanding but forgiving because it will enable adjustments and corrections in the early postoperative period. Finally, the "stress tension effect "described by Ilizarov provides a unique environment for the tissues to activate their innate biosynthetic cascade stemming the flow of the infection and facilitating the healing process. Alamar et al. report high union and low complication rates in their patient cohorts.

Provides circumferential rigid fixation and at the same time offers dynamic axial compression, allowing the surgeon to address any intraoperative error or loss of position in the early postoperative period [21]. It has been reported as a minimally invasive, secure, and successful method for treating complex ankle arthrodesis cases that allow immediate weight- bearing. [19,20] It has also been shown that tissues under tension-stress by the Ilizarov apparatus exhibit a bactericidal effect due to activation of biosynthetic processes, which help manage osteomyelitis with reduced requirement for systemic antibiotics.[22]

The spatial Taylor frame (TSF), is a new generation of circular frame (Ilizarov) apparatus that provides significant flexibility and modularity, allows early weight-bearing and reasonable patient comfort and satisfaction. There are accompanied by software that helps gradual and planned deformity correction regardless of its complexity. In their series, Om Lahoti et Al. report satisfactory results in a minimum of 7 years and a maximum of 14 years follow up [24].

Wang and colleagues [19] presented 28 cases of Charcot foot reconstruction that were, treated with equinal release, external fixation, and bone stimulation. They advocate early intervention when conservative therapy fails to halt osseous dislocation or breakdown. Advantages to this approach include the early return to weight-bearing and minimal soft tissue dissection. In their series of patients, this technique resulted in radiographic consolidation in an average of 3.1 months with no cases of further breakdown.

Conway et al. reported that the most common complication with external fixation was pin tract infection [20]. In a retrospective study evaluating circular ring external fixation, Wukich et al. [23] related a seven-fold increase in wire complications in diabetic patients versus non- diabetics. Proper early identification, mitigation, and treatment of these complications are essential to the success of the reconstruction.

3D printing surgical implants for Charcot foot surgery

It is noteworthy that state-of-the-art technologies are emerging that are expected to revolutionise the concept of Charcot foot reconstruction [25,26,27]. The 3D printed custom made implants is a prominent example of the trend.

Nowadays, it is possible to obtain high-quality multi-axial reconstruction images and analyse them with a special cluster of software arrays to manufacture custom-made implants via the 3D printing process. Of Course, this technology is still in its infancy and needs to evolve, but without a doubt, we expect to create a stirring point and achieve new milestones to diabetic foot reconstruction.

Discussion

The Charcot's foot is a devastating complication of sensory neuropathy caused primarily by diabetes Mellitus. It has a significant impact on these frail patient cohorts and therefore is a hot topic of research and debate.

The treatment's main short and long-term goal is to allow the patient with Charcot foot arthropathy the capacity to walk with a plantigrade, functional foot, improving the quality of their life and decreasing morbidity and mortality.The treatment poses a significant endeavour because the pattern of the deformities may vary significantly for each individual, and each case involves a unique array of challenges to overcome.

The surgical reconstruction deploys techniques of internal and external fixation and their combination. Which modality is more efficient and appropriate is a constant point of controversy and variation in the foot and ankle surgical community, as the scientific evidence is still conflicting and deficient in providing direct answers. From reviewing the literature, we revealed some general trends. First, many surgeons advocate the internal fixation techniques because they are straightforward and more comfortable within everyday practice. Other experts, however, prefer the external fixation modalities to address more complex deformities through staged procedures, especially if there is concern about the condition of the soft tissue envelope. It is also notable that It is a growing popularity to combine both to capitalise on each offer.

The advances in engineering and technology offer compelling solutions addressing the complex conundrum, but still, a lot of research and high-quality longitudinal studies are paramount to prove their efficacy.

Declaration of Conflict Interests

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